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The Search for Mineral Adequacy*

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An intensive and comprehensively planned program of mineral exploration and discovery is the most important single factor in maintaining an adequate supply of available minerals.

This program requires the services of a large staff of geologists and geophysicists adequately equipped with the essential instruments of exploration.

Exploration, even tho it results in substantial discoveries, will not be adequate without the aid of the miners, metallurgists, engineers, architects, and contributions from deposits in foreign countries.

Developments in mining—such as diamond drilling, block caving, and removal of overburden—have contributed toward making ore deposits of low grade economically exploitable, thereby increasing the supply of metal that can be made available.

Metallurgy is assuming an increasingly important role in bringing low-grade ores or ores of high impurity into the realm of economic ores. Examples of such contributions by process metallurgy are the combined process of treating siliceous bauxite for the production of alumina, sintering iron ore fines preparatory to smelting, and separating and recovering rare metals from complex ores.

Mineral resources in foreign countries vary in their availability and accessibility to the United States. Growth of industrial production abroad will increase competition for mineral materials among older and newly developed industrial nations; also nations will tend to reserve for their own use minerals hitherto exported. Availability of foreign minerals may be further limited or curtailed by adverse foreign exchange policies or by hostile intent. International agreements, particularly with nations geographically accessible, mutually advantageous to each, should be encouraged.

Ore Flow

The United States uses such large quantities of metals and minerals in today's economy that we may well raise the question as to the mining industry's ability to sustain the present volume of mineral flow and to provide an increasing flow in the future.

The American citizen, on the average, now uses minerals or mineral products at the following annual rates:

	Pounds per year
Steel	1,260
Lead	16
Copper	23
Zinc	16
Aluminum	18
Chromium	13
Manganese	8.7
Nickel	1.3
Tin	1.2
Cement	520
Common salt	520
Phosphate rock	130
Lime (other than for cement)	85
Sulphur	71

* This material is taken from "The Search for Mineral Adequacy" which was published in the November, 1959, issue of *The Journal of Geography*.

Other metals consumed in smaller amounts are antimony, magnesium, molybdenum, cadmium, cobalt, tungsten, mercury, beryllium, vanadium, niobium, and bismuth.

Mineral and Metal Inventories

Appraisals of mineral supply have been made from time to time, in varying degrees of detail, for the United States and several other nations of the world as well.[1] In comparing the known inventories of minerals and the current rate of consumption, this fact is clearly apparent: for many metal and mineral supplies, there is not enough proven ore for a sustained production until the year 2000 A.D. or even sooner. The search for additional mineral supplies, together with a continued search for more efficient use of each pound of metal that is used in economic production, must go on, possibly with increasing intensity.

The Mineral Reserves Inventory

This brings us to the question: what are our mineral resources? A mineral deposit is rarely a homogenous ore body with well defined boundary lines. An estimate of the mineral resources of a nation or nations is necessarily indefinite and indeterminable. The mine operator, confronted with the necessity of making a profit on his operation, measures the ore in a deposit as the quantity that he can profitably recover under existing operating costs and market prices. The miner refers to an ore deposit in which the quantity is definitely established as "proven ore." When he is uncertain of the extent of the ore body, the miner introduces the terms "probable ore" and "possible ore," depending upon whether geological conditions differ slightly or vary widely from conditions that determine "proven ore."

This classification applies only to individual ore deposits; it is not suitable for an ore resource appraisal intended to cover a nation or other large political or geographic units. For such purposes the staffs of the U. S. Geological Survey and the Bureau of Mines have adopted a classification that has been very useful in its application in the United States and is getting world-wide acceptance. This classification nomenclature adopted by the bureaus is as follows: (1) measured reserves, (2) indicated reserves, and (3) inferred reserves.

The definitions of the terms used in this classification are as follows:

(1) Measured reserves are those for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely and the geologic character is so well defined that size, shape, and mineral content are well established. The computed tonnage and grade are judged to be accurate within limits which are stated, and no such limit is judged to be different from the computed tonnage or grade by more than 20 per cent.

(2) Indicated reserves are those for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established thruout.

(3) Inferred reserves are those for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves should include a statement of the specific limits within which the inferred material may lie.

A modification of this classification is proposed by Blondel and Lasky[2] in which they suggest that the terms "measured" and "indicated" be abandoned and replaced by the term "demonstrated" reserves. They define this term as follows: demonstrated reserves are those for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. They may include some ore bodies where the sites for inspection, sampling, and measurement are spaced so closely and the geologic character so well defined that size, shape, and mineral content are well established, and other ore bodies where the sites available for inspection, sampling, and measurement are too widely or otherwise inappropriately spaced to permit the bodies to be outlined completely or the grade established thruout.

In the formulation of a national minerals policy, the purpose of which is to assure, if possible, a sustained flow of mineral supplies, the equation formulated by Blondel and Lasky serves a very useful purpose. This equation reads:

Resources = reserves + potential ores

in which reserves are comparable to the "proven ore" as defined by the miner or "measured reserves" as used by the economic geologist. Potential ores include the vast tonnages of earth material beyond the realm of proven ore but that have a wide range of economic worth. Potential ores range in quality from submarginal ores that become economically useful with a slight rise in price or improvement in technology to metal-bearing material that is not usable in the foreseeable future.

In order to accommodate the wide variety of mineral material into a more workable equation, Blondel and Lasky [2] modify their first equation to read:

Resources = reserves + marginal resources + submarginal resources + latent resources.

Marginal deposits are defined as ores that are exploitable under slightly better conditions.

Submarginal deposits are defined as ore sufficiently extensive and of a grade that can be exploited but only under distinctly more favorable economic conditions or technological improvements.

Latent resources include all rocks beyond the first two categories. It is toward the second, third, and fourth groups on the right side of the equation that the efforts to strengthen the mineral supply situation must be directed. It is these areas into which the miner must move, sooner or later, when the limited supply of ore in "proven reserves" is exhausted. For some minerals the supply of "proven ore" is so large that the step into the unproven zones may be long deferred.

The Need for Mineral Exploration

The increasing pace of mineral consumption confronts us with the question not as to whether we can maintain the pace of mineral supply, but rather *how*.

The Advisory Committee on Mineral Research [3] has recently pointed out that 90 per cent of our metallic wealth has come from a scant 1,000 square miles of our national domain. At the rate we are extracting what remains in this 1,000 square miles, it behooves us to look for the next 1,000 square miles. Our economy and even our survival depend upon the success of our quest.

The Materials Policy Commission has assessed the status quo and suggested the kind of action program that must be undertaken. Stop-gap measures such as stock piling and encouragement of new productive capacity have been inaugurated.

Intensified exploration and fundamental research in the origin of ore deposits are solely needed. A diagnostic approach to the problem of ore body location may be of aid. It is more than likely that mineralization yields several series of diagnostic features that, if recognized and understood, would lead the expert to hidden ore bodies. "Metamorphic processes produce chemical effects that are reasonably well known and understood within, and in the immediate vicinity of, ore bodies that are being exploited. Yet what mineralogic and geochemical alterations do they produce in country rock of diverse types at varying distance from the source? If the alteration is consistent with each genetic type of mineralization or with any single type, a clue is available to localize the search for economic mineralization that has not yet been exposed by erosion or that has suffered the accident of burial beneath an extraneous overburden." [4]

The Advisory Committee has recommended the inauguration of several studies in geology, geophysics, and geochemistry designed to discover and determine the gravitational, seismic, magnetic, electrical, radioactive, geothermal and tectonic characteristics that may prove diagnostic in pinpointing the position of hidden mineral wealth. The Committee's suggested program is to bring new mineral deposits within the realm of economic exploitation. The goal is an aggregate of integrated knowledge, new and old, so marshalled that it can be used to discover and recover buried mineral wealth necessary for the perpetuation of an industry that is the bulwark of our industrial strength.

The Problems and Methods of Mineral Exploration

Methods of ore exploration are well defined. Geological exploration, assisted by topographic mapping, geophysics, and photogeology, is still the most important method for the systematic examination of earth material. Photogeology is coming into play in a big way in exploring 370,000 square miles of the Canadian wilderness north of the Great Lakes with 400,000 square miles of extensions planned. Several mining companies have joined in a two- to three-year project combining electromagnetic and magnetometer data, plain and color photography and the skills of geologists, soils engineers, hydrologists and foresters in the preparation of one-mile to one-inch mosaics. Geologic data from all known sources will be added. At a cost of a few million dollars, exploration of a vast region may be set ahead a decade or two.

More recently, methods of geophysical exploration have been introduced and are proving highly useful in locating some types of mineral deposits. The power of geophysics as a tool in mineral exploration stems from the fact that various physical phenomena associated with many mineral deposits can be detected at a substantial distance from the deposits.

The physical characteristics that may be observed in geophysical surveys are: (1) magnetic susceptibility, (2) specific gravity, (3) electric conductivity, (4) elasticity, (5) radio activity. The methods of explorations are thus divided into magnetic, gravimetric, electric, seismic, and radioactive.

Geophysical methods have been singularly successful in the location of petroleum deposits and iron ores but they have not been so successfully applied to copper, lead, and zinc, altho the magnetometer was successfully used in determining the shape and direction of the ore-bearing structure in the Broken Hill lead and zinc district.

The development of tools to locate concealed deposits of copper, lead, and zinc, whose existence is suspected on theoretical grounds, will be a difficult task, as the targets sought are much smaller than those sought by the petroleum geophysicist, and the differences to be measured in the physical properties of favorable or unfavorable rock are also minute. Research aimed at applying modern knowledge to making geophysical techniques simpler, cheaper, and more directly useful to exploration geologists could contribute to the nation's mineral resource picture.

The unfavorable discovery record in the nonferrous metals, today is in part due to the fact that the "pickings" are not what they used to be. Reserves decline each year and new resources on which we must depend in the future are sought more and more abroad than at home. Possible awareness of our situation may be responsible for the emphasis that recent geological papers have placed upon matters of research. Mining geologists are increasingly aware that our advance in our understanding of the genesis of ore deposits in the past decades has not been notable.

Geochemical, radioactivity, and other methods are coming into the picture. For example, discovery that the ratio of the heavy isotope of oxygen (oxygen 18) to the light variety of the element (oxygen 16) varies directly with its distance from an ore deposit was announced recently by scientists from the California Institute of Technology. According to Dr. Robert P. Sharp, chairman of the geological division, the find should provide a valuable tool for investigating the origins of the earth's crust. And "it is quite possible," he added, "that this variation in oxygen isotope ratios will become extremely important as a means of locating 'hot' spots of rock alteration that may be associated with ore deposits." It could prove to be the basis "for one of the most significant contributions to ore prospecting in the past fifty years." [5]

The problem of mineral exploration is not only one of finding a method, but also of implementing these methods into an effective program of ore discovery.

Explorers can operate successfully only with adequate finances, favorable political conditions, and good working relations between industry and government and among local and federal governments.

The individual prospector as the discoverer of mineral deposits has passed from the scene, leaving the field to the privately owned mining companies, state surveys, the federal survey, and, recently, international co-operation in geological exploration.

Exploration for mineral deposits within well-known mineral districts is usually carried on by mining companies that operate in and are familiar with the geologic characteristics of the district. By reason of their experience, mining companies are best equipped to enlarge the area of "proven ore" in an economical manner.

The public phase of mineral exploration comes into being where areas larger than a single deposit or districts of associated deposits are involved. There may be mineral deposits in the old rocks that are buried beneath the sediments of the Mississippi and Missouri valleys. Private companies cannot afford to search for such possible deposits, yet with increasing geological knowledge and better exploratory tools, they might be found. The large cost of such exploration can be supported only by public funds. In some cases effective exploration can best be done by state surveys, as for example a study of coal reserves. In cases where knowledge of geologic structure over a large area is essential to location of hidden mineral resources, the work may have to be undertaken by a federal agency.

The crux of the problem is one of an assured continuing program of discovery and exploration. This involves not only adequate funds and competent staffs but also a scale of operations which will yield a return in new metal discovered that will at least replace the amount consumed. Requirements go beyond the need of technical methods and staffs; it requires a public enlightenment which will, without stint, endorse the public expenditures that are essential to maintain an adequate program. It must be remembered that in the United States, a large proportion of the more obvious deposits have been discovered and that finding any remaining concealed or poorly exposed deposits will be a relatively slow process.

Prospects for Discovery

Expenditures of public funds for long range, comprehensive, exploratory programs must be justified on the basis of anticipated results. Petroleum geologists appraise future discovery by assuming that known petroleum-producing areas are a general measure of the unexplored but geologically favorable regions. Wrather suggests that a similar formula might be developed for the porphyry coppers, much of the lead and zinc in the United States, most of its manganese, mercury, iron, and fluorspar. This method could also be applied to unexplored portions of the Canadian pre-Cambrian shield and also to unexplored parts of Brazil.

The Contribution of Technology

Technology, as related to the mineral industries, is here defined to include mining, metallurgy, manufacturing, architectural design, and substitution. Altho technology cannot add to the sum total of materials in the earth's crust, it can devise methods of bringing hitherto inaccessible minerals into available form and of increasing the usefulness of the metal or mineral after it has been mined. We may truly say that technology is a "multiplier of resources."

Contribution of Mining Engineering

With the expectation that the rich and easily accessible ore bodies have been discovered and that future additional supplies of metal will come from low-grade or deep-seated ore bodies, the problem becomes one of recovering such ores at a cost that can be borne by consuming industries. In the United States, where labor is highly paid, the trend is toward modifying mining methods to permit greater mechanization. Obviously low-grade deposits cannot be moved profitably by high-cost methods. Modified mining practice is paying increased attention to working of ores from the surface by stripping overburden. This is particularly true in coal and in iron and copper ores. Ore deposits are now being mined from surface workings that would have been developed by underground mining ten years ago.

Open-stope and undercut-block caving methods are gaining favor as low-cost operations where underground mining is necessary.

Contribution of Metallurgy

Under metallurgy is included mineral dressing, process metallurgy, metal processing, application metallurgy, chemical metallurgy, and physical metallurgy.

The coming use of lower grade ores, accompanied by higher cost materials and possible scarcity, imposes duties upon the metallurgist to solve problems involving both technology and cost. It seems apparent that the production of minerals in future years will require more and more man-hours of labor for each unit of metal recovered. This is true whether it means more man-hours invested in the capital requirements to bring a deposit into production or the current man-hour needs to produce ore in an operating project. This being the case, there is less material to go around for a given day's labor and an increasing need for economizing in use. The problems range from the mechanical handling involved in the separation of metal-bearing minerals to the development of metallurgical processes for the production of the rare metals in nearly pure form. Among the examples we may cite in which the metallurgist or the chemist brought rock materials into the realm of commercial ore is the process of separating magnetic minerals from taconite ore, the processing of high-silica bauxite ores by the "combination process" in which the alumina in the red mud is recovered, the saving of iron ore fines by the sintering process, and the recovery of sulfur from "sour" gas from refinery gases, from reclaimed sulfuric acid, and from coal brasses. A contribution to availability of iron is the progress that is being made in making metallurgical coke from coals hitherto non-coking. This is of special significance in the anticipated decline of presently acceptable coking coal reserves. Recent developments in pig iron production very definitely conserve both fuel and metal. Beneficiation of ores including sizing and agglomeration, high top pressure operations, introduction of steam into the blast, introduction of oxygen into the blast, preheating the blast above conventional temperatures, all have the effect of lowering the coke rate.

Another contribution of metallurgy to increased metal supply is in the development of new alloys. Numerous experiments have been conducted during the past few years dealing with addition of rare earths (metals and oxides) to iron and steel. As an example, extremely small percentages of boron added to low-carbon and alloy steels increase their ability to harden and save alloying metals such as chromium, nickel, molybdenum, all normally used in much greater quantities. Even more significant is the saving in such imported alloying metals as chromium and nickel. One ferro alloy manufacturer claims that the use of rare earths in steel could result in saving 100,000 tons of manganese per year in the United States. Use of solar furnaces in developing and producing "cermets" and other special alloys is of particular significance because of the current interest in such high-temperature materials for use in jet and rocket engines.

A particularly difficult metallurgical problem is the recovery of the so-called rare metals. Some of these metals have physical and chemical properties that make them useful or essential where resistance to high temperatures, as in the gas turbine or the jet engine, is required. Again certain among the minor metals, such as hafnium, cadmium, zirconium, are useful or essential in the production of nuclear energy.

In general the rare or minor metals are difficult to recover from their native state—a problem for the metallurgist.

Multiple Recovery of Metals and Minerals

One aspect of ore dressing and process metallurgy that may receive increasing attention in the future is the joint recovery of more than one ingredient from a complex ore. Among such developments, the recovery of both fluorine and uranium oxide from phosphate rock is under consideration or in production. Fluorine supplies will become increasingly critical as a basis for manufacturing synthetic cryolite as aluminum output increases and supplies of natural cryolite decline. Fluorine can be recovered from phosphate rock in a wet-process method of preparing superphosphate. At the same time the minute quantities of uranium oxide present in phosphates can also be recovered, thus adding to the total reserve of this needed energy-source material.

Cement plants in Europe are recovering sulfur from gypsum while they produce cement.

Treatment of the whole rock may be particularly significant in a search for minor or trace elements, none of which are present in anything like present commercial amounts. The Phosphoria formation of the Rocky Mountain Region, which includes most of the high-grade phosphate deposits of the United States, also has significant trace amounts of uranium, vanadium, the rare earths, silver, nickel, zinc, and molybdenum, as well as appreciable quantities of fluorine and sulfur. The recovery of these other ingredients may be an attractive target for research scientists and technologists at some future date.

Construction

In the field of construction, the architect can help increase the per-pound service of steel, for example, by carefully designing steel members to a size commensurate with the load to be carried. This practice is followed extensively in Europe where steel costs more than in the United States. Also concrete can be substituted for steel in large buildings, as is done in Latin American nations where steel is also somewhat scarce. Prestressed concrete, the use of which is expanding rapidly, can in some instances be advantageously substituted for steel.

Substitution

Much work has been done in investigating the possibilities of substituting abundant materials, such as aluminum and magnesium, for less abundant materials, particularly copper. Some results have been achieved. What is needed here is a study of the fundamental physical and chemical properties of the basic components of our raw material supply. Renewable materials, such as wood, may continue to play an important role among our industrial material needs. Among the little used metals, silicon, one of our most abundant materials may, upon investigation, occupy a larger role. It may be possible that scientists and engineers may create out of abundant materials new substances that have predictable, specific properties.

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The Mineral Industry of Virginia in 1959 (Preliminary)

The value of mineral production in Virginia in 1959 totaled $221 million, an increase of 11 percent over 1958, according to estimates by the Bureau of Mines, United States Department of the Interior (Area Report H-152). Increased building activity and highway construction, greater demand for coal for steam and other industrial purposes, and higher metal prices were the chief contributing factors to the higher value in 1959.

Output of coal, by far the most important mineral produced in Virginia, rose 9 percent to 29.2 million short tons, only 1 percent less than the record year, 1957 (29.5 million tons). Production of natural gas dropped sharply compared with 1958 while the small output of petroleum remained approximately the same in 1959 as in 1958.

Among the metallic minerals, output of recoverable zinc in 1959 rose 7 percent to 19.7 thousand short tons and its value jumped even more due as much to a 12 percent rise in average price compared with 1958 as to the increase in output. Recoverable lead, however, showed a moderate decline in both quantity and total value, despite a small increase in the average price per ton. Production of manganese ore continued at a low rate throughout the year, all tonnage produced consisting of 35 percent or more manganese content. Combined output of ilmenite and rutile (titanium concentrate) was approximately the same as in 1958.

The value of all nonmetallic minerals used primarily in building and highway construction, except for stone, increased compared with 1958, clays (5 percent), sand and gravel (16 percent), portland cement (11 percent), and masonry cement (17 percent). Output of gypsum and stone also were higher in tonnage than in the preceding year. Aplite, kyanite, iron ore for pigments, pyrites, and salt also showed moderate gains over 1958, in response to greater ceramic and chemical activity in 1959.

Division of Mineral Resources
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Form 3547 Requested

Listing of Consultant Geologists

The Virginia Division of Mineral Resources is compiling a list of geologists who are available to conduct surveys, to evaluate rock and mineral deposits, and to advise on problems concerned with the mineral industry in Virginia. This listing has been brought about by individuals and companies who have requested names of geologists that perform consulting services in Virginia. In the event that some geologists did not receive the form prepared by the Division a copy of the form is printed below. If you are available to do consulting work and wish your name to be incorporated in this listing, we would appreciate your furnishing us with the information requested on the form below:

Availability of Geologists To Do Consulting Work in Virginia

Your name:

Telephone No.:

Address:

1. Are you available to do consulting work in Virginia in addition to your regular employment? Yes .... No ....

   If yes, your employer's name:

   address:

   title of your position:

2. Are you a self-employed consultant?

   Yes .... No ....

3. If answer to question 2 is "No," is the company in which you are regularly employed a consulting firm? Yes.......... No..........

   If yes, name of company:

   address:

   title of your position:

   number of geologists..........

   number of engineers.......... regularly employed by the firm

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